

NASA Technical Memorandum 105310
AIAA-91-3528

111061

P.13

An Overview of the Lewis Research Center CSTI Thermal Management Program

Albert J. Juhasz
Lewis Research Center
Cleveland, Ohio

Prepared for the
Conference on Advanced Space Exploration Initiative Technologies
cosponsored by AIAA, NASA, and OAI
Cleveland, Ohio, September 4-6, 1991



(NASA-TM-105310) AN OVERVIEW OF
THE LEWIS RESEARCH CENTER CSTI
THERMAL MANAGEMENT PROGRAM (NASA)
13 p

N92-31916

Unclass

G3/20 0111061

AN OVERVIEW OF THE LeRC CSTI THERMAL MANAGEMENT PROGRAM

Albert J. Juhasz

National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

ABSTRACT

This report presents an integrated multi-element project effort, currently being carried out at NASA LeRC, for the development of space heat rejection subsystems, with special emphasis on light weight radiators, in support of SEI power system technology, and in particular the SP-100 program. Principal project elements include both contracted and in house efforts. Included in the first category are two contracts, with Rockwell International (RI) and Space Power Incorporated (SPI), aimed at the development of advanced radiator concepts (ARC), and demonstration of a flexible fabric heat pipe radiator concept being conducted by DOE/PNL under an interagency agreement. In house work is designed to guide and support the overall program by system integration studies, heat pipe testing and analytical code development, radiator surface morphology alteration for emissivity enhancement, and composite materials research focussed on the development of light weight high conductivity fins.

INTRODUCTION

Ongoing "CSTI Thermal Management" related work at LeRC is an integral part of the NASA CSTI High Capacity Power Program, and specifically the TriAgency (DOD/DOE/NASA) SP-100 nuclear reactor space power program [1].

The goal of the LeRC thermal management effort is to develop space radiator and heat rejection system concepts, optimized for a spectrum of space power conversion systems for planetary surface (lunar base) and nuclear propulsion applications for deep space long duration missions needed for the Space Exploration Initiative [2]. The power, or energy, conversion system concepts range from static systems such as thermoelectric or thermionic, to dynamic conversion systems based on heat engines such as the Stirling engine or the closed cycle gas turbine also

known as the Closed Brayton Cycle (CBC). Although the principal heat sources for these systems are nuclear [3], the technology being developed for the heat rejection subsystem is also applicable to low earth orbit (LEO) dynamic power systems with solar energy input, using a concentrator and heat receiver, studied as alternatives to photovoltaic power systems [4]. The performance goals for the advanced radiator concepts being developed are lower radiator mass (specific mass of near 5 kg/m²), greater survivability in a micrometeoroid or space debris environment (up to 10 years) at a sub-system reliability of 0.99 or higher. These performance goals may be realized by radiator segmentation and parallel redundancy, using a large number of heat pipes. Achievement of these goals may lead to a reduction of the SP-100 radiator specific mass by a factor of two or more over the present baseline design.

The project elements, shown in figure 1, include development of advanced radiator concepts under LeRC managed contracts and a NASA/DOE interagency agreement, as well as in house work directed at radiator design for optimum power system matching and integration. Also, in house and university supported heat pipe research and development is being carried out, comprising both analytical computer code development for predicting heat pipe performance, both under steady state and transient operating conditions, along with experimental testing for the purpose of validating analytical predictions.

Contributing to the in-house advanced development program is continued research on radiator surface treatment techniques (surface morphology alteration), aimed at enhancing surface emissivity and resistance to atomic oxygen attack.

The development of new radiator materials showing high strength-to weight ratio, and high thermal conductivity, such as graphite-carbon and graphite-copper composites for light weight radiator fin applications is another major program objective.

The project plan to accomplish the above program objectives is shown in figure 2. Note that due to funding constraints, the development of far term innovative radiator concepts, such as liquid droplet radiator (LDR) or moving belt radiator (MBR), is not being actively pursued at the present time. Instead, technologies capable of development before the end of the decade are being concentrated on for both surface power and nuclear electric propulsion (NEP) applications.

The remainder of this report will be devoted to a status report on the major project elements, concentrating on the contracted efforts which account for the major portion of the baseline budget.

Advanced Radiator Concepts Development Contracts

The Advanced Radiator Concepts (ARC) contractual development effort is aimed at the development of improved space heat rejection systems, with special emphasis on space radiator hardware, for several power system options including thermoelectric (T/E) and Free Piston Stirling (FPS). The targeted improvements will lead to lower specific mass, i.e. lower mass per unit area, higher reliability and survivability in a natural space environment, thereby leading to longer life for the power system as a whole.

Specific objectives are to achieve specific mass values $< 5 \text{ kg/m}^2$ attained with radiator surface emissivities of 0.85 or higher at typical radiator operating temperatures, and reliability values of at least 0.99 for the heat rejection subsystem over a ten year life. The above figures of merit represent a factor of two improvement over the currently considered heat rejection subsystem for SP-100, and even greater improvement factors for state of the art heat rejection systems used in current spacecraft applications.

Phases I, II, and III of the ARC contracts have been completed by both contractors, SPI and RI. Based on phase III results, both contractors were selected to proceed into component level development, fabrication, and demonstration, to be accomplished under phase IV over a two year period, to be concluded in FY 93.

Both, a high temperature heat rejection option (800K to 830K) applicable to T/E power conversion systems, and a low temperature option (500K to 600K) applicable to Stirling power conversion systems, will be developed by SPI, while RI will concentrate only on the high temperature option for T/E power systems.

Contract NAS 3-25208 with SPI

Among the advanced concepts proposed by SPI are the "Telescoping Radiator" [5,6] for multi-megawatt thermoelectric (TE) or liquid metal Rankine (LMR) power systems (figure 3) and the "Folding Panel Radiator" [6], shown in figure 4, for the 500 K to 600 K heat rejection temperature range. The latter concept was based on a pumped binary lithium/sodium potassium (Li/NaK) loop, motivated by a desire to avoid the need for mercury heat pipe radiators originally planned for a Free-Piston Stirling (FPS) power system which rejects heat in the above temperature range. A detail of a typical Li/NaK heat rejection loop, which also utilizes high conductivity fins for the heat transport is shown in figure 5.

As indicated in figure 6 (a) the advantage of using a lithium-NaK mixture, rather than NaK alone (melting point 261 K), lies in its combining the high heat capacity and low pumping power of Li (melting point 452 K) with the liquid pumping capability of NaK, down to its freezing temperature of -12 C.

To illustrate operation of this binary loop during system start-up and shutdown, a brief explanation is in order. During startup (Li frozen) liquid NaK would be pumped through the inner cores of radiator tube passages in hydraulic contact with the frozen layers of Li coating the inner passage surfaces. As the NaK is heated during power system startup, it will eventually melt the solid Li shells by direct contact forced convection heat transfer, progressively mixing with the NaK to form the all liquid Li/NaK coolant. Conversely, on shut-down of the power system, the molten lithium with its higher freezing point will selectively "cold trap" or freeze on the inner passage surfaces as their temperatures drop below 452 K, while the NaK continues to be pumped in its liquid state through the inner cores of the radiator passages.

Initial tests conducted thus far, using a trunnion mounted test chamber to isolate gravity effects (figure 6b), have demonstrated the feasibility of the concept. In particular the feasibility of a heat rejection system based on a binary Li/NaK pumped loop was demonstrated during transient operating conditions representative of both the cooldown (Li freezing) and the warmup (Li melting) phases of typical alkali metal heat rejection pumped loops. The thawing process during the warmup condition had to be controlled very closely to avoid plugging of the flow loop due to molten Li re-freezing downstream at certain operating conditions. Current efforts focus on widening the

operating envelope by a variety of techniques. One of these involves the use of fine mesh screens which act as semi-permeable membranes to NaK under certain operating conditions.

The contractor also completed a two dimensional computer analysis of the cooldown (freeze) and the warmup (thaw) process including color graphics output. Although the flat flow channel cross sectional geometry assumed in the analysis deviated from the cylindrical flow channel used in the experimental loop, this computer code nevertheless permitted visualization of basic phenomena taking place within the binary loop during the warmup and cooldown periods. A video tape was produced illustrating several cases with and without plugging of the flow channel due to lithium freezing over the entire channel cross section.

High Conductivity Fin Development

Progress was also made by SPI in identifying potential subcontractors, namely Applied Sciences Inc. (ASI) and Science Applications International Co. (SAIC), with demonstrated capabilities in the development and fabrication of high thermal conductivity composite materials for space radiator fin applications. In particular, ASI has produced a composite by CVD densification of closely packed (up to 60 vol. %) vapor grown ceramic fibers (VGCF) which was shown to have very high thermal conductivity, near 560 W/m K, at a density of 1.65 g/cc. Use of composite materials which exhibit specific thermal conductivity values at this level for heat pipe fin applications has the potential of reducing radiator specific mass by over 60 percent for radiators that are radiative heat transfer surface limited, i.e. no heat transfer limitations exist at the secondary cooling loop/heat pipe evaporator surface interface.

Technology requirements for joining the high conductivity fins to the heat pipes by advanced brazing or welding techniques have also been identified.

Contract NAS 3-25209 with RI

A sketch of the "Petal-Cone" radiator concept being developed at RI [7] is shown in figure 7. Since each of the "petals", or radiator panels, are composed of a large number (384) of variable length C-C heat pipes mounted transverse to the panel axis, a major objective of this effort is the development of these integrally woven graphite carbon tubes with an internal metallic barrier that is compatible with the intended potassium working fluid.

Carbon-carbon (C-C) heat pipe tube sections with integrally woven fins were fabricated under phase III. Highlights of the fabrication process are illustrated in figure 8. Because of its low cost, commercial availability, and ease of weaving a T-300 fiber was selected for this demonstration of C-C heat pipe preform fabrication. This PAN fiber was judged to represent a tradeoff between high elastic modulus, and consequently ease of handling and weaving, at medium thermal conductivity, as contrasted to some very high conductivity fibers which, however, may be brittle and difficult to weave.

Several fiber architectures were investigated before settling on the angle interlock, integrally woven concept. In this design, the axial fiber bundles, referred to as warp weavers, are woven in an angle interlock pattern, repeatedly traversing from the ID to the OD surface of the tube. An unfilled "Novolack"/resole prepreg resin was selected for prepegging the woven preforms followed by a low pressure impregnation and carbonization process for densification of the composite.

Considerable progress was made in the development of internal metallic coatings to ensure compatibility of the heat pipe surface with the potassium working fluid. A coating consisting of a 2 to 3 micron rhenium sublayer with a 70 - 80 micron niobium overlayer emerged as the final recommended coating design. Due to funding and time limitations, however, this final coating design and the recommended method to achieve it by a novel chemical vapor deposition (CVD) process utilizing a moving heat source could not be fully implemented during phase III. Other coating approaches which were tried achieved incremental improvements over each previous coating attempt, but a constant thickness coating over the full length of the tube without any flaws or imperfections could not be achieved.

Due to the problems encountered with achieving a flawless metallic coating on the internal C-C tube surface, with the inception of phase IV a technical direction was issued to the contractor, which requires that the safe containment of the heat pipe working fluid be accomplished by means of a metallic liner, rather than the metallic coating that had been under development during phase III.

Concurrently with this task a high temperature braze or other joining process needs to be developed, in order to insure good mechanical and thermal contact between the thin metallic liner and the C-C internal

tube surface. Bonding of the entire liner surface to the tube needs to be achieved to prevent partial separation and collapse of the liner at conditions where the external atmospheric pressure exceeds the internal pressure of the working fluid.

Concerning the integral fin weaving process using T-300 fibers, improvements will lead to the elimination of the internal cusp formed at the fin-tube interface. This will be accomplished by changing the weave architecture, so that the outer rather than the inner plies will be used to form the fins.

It should be noted that with the funding allocated to this contract the integral fin weave will be demonstrated with T-300 fiber yarn only.

Although the T-300 fiber resin matrix composite has a low specific thermal conductivity, the integral fin weave advantage eliminates the need for developing fin-to-heat pipe joining techniques. Moreover, perfecting the integral fin weave technique with yarn spun from the highly pliable T-300 fiber will pave the way for tackling the weaving process with higher conductivity but lower flexibility fibers, which may be carried out under a future development program.

Light Weight Advanced Ceramic Fiber (ACF) Heat Pipe Radiators

The objective of this joint NASA/LeRC and Air Force program with Pacific Northwest Laboratory (DOE/PNL) is to demonstrate the feasibility of light weight ceramic fabric/metal liner heat pipes for a wide range of operating temperatures and working fluids. Specifically the NASA LeRC objectives are to develop this concept for application to Stirling space radiators with operating temperatures below 500K, using water as the working fluid. The specific mass goals for these heat pipes are $< 3 \text{ kg/m}^2$ at a surface emissivity of > 0.85 .

Several heat pipes were built using titanium and copper foil material for containment of the water working fluid. A heat pipe with an eight mil Ti liner was demonstrated at operating temperatures up to 475 K at the 8th Symposium on Space Nuclear Power Systems (SSNPS) in Albuquerque, in early January 1991.

An innovative "Uniskan Roller Extrusion" process has been developed at PNL and used to draw 30 mil wall tubing to a 2 mil foil liner in one pass. Moreover, this process eliminates the need for joining the thin foil section to a heavier tube section for the evaporator section which needs to be in tight mechanical and

thermal contact with the heat rejection system transport duct.

The heavier end sections are also used for attachment of the end caps.

The liner fabrication technique is expected to have a wide range of applications, beyond the scope of this program.

The water heat pipes fabricated for LeRC have been subjected to a test program to evaluate performance and reliability at demanding operating conditions, including operating pressures up to 25 bar. Tests were conducted with and without wicks with the heat pipes in various gravity tilt orientations from vertical to horizontal. In addition a number of wick designs were tested for capillary pumping capability, both in ground test and under low G conditions produced during KC-135 aircraft testing.

The work was reported in a paper presented at the 27th National Heat Transfer Conference (NHTC) [8].

Future thrusts of this work will be to perfect the heat pipe fabrication procedure, using very thin (1 to 2 mil) foil liners, internally texturized by exposure to high pressures.

Because of the high operating pressures, plans will be developed to perform hyper-velocity and ballistic velocity impact tests, in order to ascertain if secondary fragments from a penetrated heat pipe will result in failures of neighboring heat pipes.

Another major challenge will be to design a heat pipe with high conductivity, light weight fins, as a first step toward the fabrication of light weight radiator panels.

Based on results from the above a preliminary design of a representative radiator panel and radiator subsystem will be designed, including heat exchanger ducting, pumps and flow control devices. Fabrication and testing of this design is expected to be carried out in a later phase of this work.

Supporting Project Elements

Space limitations prevent a detailed discussion of the remaining project elements referred to in figure 1. However, a brief paragraph highlighting each of these activities is warranted.

As mentioned previously, the system integration

studies performed in house, serve to guide the overall TM work by providing the proper framework for it. As shown in [9], for example, a liquid sheet radiator (LSR) with lighter specific mass than a heat pipe radiator, will not necessarily benefit all power conversion systems equally. As shown in the reference, the LSR concept is not suited to the heat rejection temperature profile of a CBC power system. However, it does work well with a Stirling power system which rejects heat at a near constant temperature. As a further example of how radiator-power system integration studies are used to ascertain radiator induced power system performance degradation, the reader is referred to figure 9. The curves shown here illustrate the reduction in power output and efficiency for both Brayton and Stirling power systems resulting from a loss of radiator area, caused for example by micrometeoroid damage. It is reassuring to note, that even with a loss of 50 % of radiator area, a Stirling is still capable of producing over 75 % of its design power, while a CBC produces over 65 %.

A typical example of radiator surface morphology alteration by arc texturing for emissivity enhancement purposes is shown in figure 10. With the arc texturing apparatus shown in figure 10 (a), the adjoining bar chart, figure 10 (b), shows the surface emittance results achieved with various arc current values for graphite-copper samples produced under the in-house materials program. Additional details on the emittance enhancement process and measurement techniques are included in [10]. A brief overview discussion of emittance enhancement by atomic oxygen (AO) bombardment is also given in [1].

Heat pipe performance modelling, both under steady state and transient operating conditions is being conducted in-house and under university grants respectively, with UCLA, UNM and WSU. The objective of this work is to develop a capability to analytically predict transient operation of heat pipes, particularly during the startup and cooldown phases. An especially important feature of this work is the development of an analysis code capable of modeling startup with the working fluid initially in the frozen state for a variety of working fluids, including water and liquid metals. Working versions of the codes have been developed, and validation of predicted performance by laboratory testing of heat pipes is under way at LeRC, LANL, and WRDC. Efforts have also been initiated to compile an experimental database by a systematic literature search and close communication with other researchers in the field.

CONCLUDING REMARKS

The LeRC CSTI Thermal Management Program is designed to combine a number of project oriented elements to accomplish the overall objective of reducing radiator specific mass by a factor of two at a subsystem reliability of 0.99 over a ten year life. Although the main focus is on support of the SP-100 program by advances in heat rejection technology, the concepts and hardware developed under this program are expected to benefit space power systems in general, ranging from solar dynamic systems with a power level of a few kW to multi-megawatt power systems with nuclear heat sources for planetary surface and nuclear (electric) propulsion applications. With the focus on the SP-100 program the project schedule goals are that the major technology advances be ready for implementation before the end of the decade, so that NASA's and the nation's long term goals in space exploration and utilization may be realized.

REFERENCES

1. Winter, J. M. "The NASA CSTI High Capacity Power Program" AIAA/NASA/OAI Conference on Advanced SEI Technologies, Cleveland, Ohio, Sept 4-6, 1991.
2. Bennett, G. and Cull, R. C. "Enabling the Space Exploration Initiative: NASA's Exploration Technology Program in Space Power" AIAA/NASA/OAI Conference on SEI Technologies, Cleveland, Ohio, Sept 4-6, 1991.
3. Juhasz, A. J. and Jones, B. I. "Analysis of Closed Cycle Megawatt Class Space Power Systems with Nuclear Reactor Heat Sources" Proceedings of the Third Symposium on Space Nuclear Power Systems, Albuquerque, NM, Jan. 13-16, 1986.
4. Brandhorst, H. W.; Juhasz, A. J.; and Jones, B. I.; "Alternative Power Generation Concepts in Space", NASA TM-88876 (1986).
5. Begg, L. I. and Engdahl, E. H. "Advanced Radiator Concepts - Phase II Final Report for Spacecraft Radiators Rejecting Heat at 875 K and 600 K" NASA Contractor Report 182172, May 1989.

6. Koester, K. and Juhasz A. J. "The Telescoping Boom Radiator Concept for Multimegawatt Space Power Systems" AIAA/NASA/OAI Conference on Advanced SEI Technologies, Cleveland, Ohio, Sept 4-6, 1991.
7. Rovang, R. D. et al. "Advanced Radiator Concepts for SP-100 Space Power Systems", NASA Contractor Report 182174, October 1988.
8. Antoniuk, Z.I., Webb, B.J., Bates, J.M., Cooper, M.F., and Pauley, K. A. "Testing of Advanced Ceramic Fabric Wick Structures and their Use In a Water Heat Pipe" 27th NHTC, Minneapolis, Minn., July 28-31, 1991.
9. Juhasz, A. J. and Chubb, D. L. "Design Considerations for Space Radiators Based on the Liquid Sheet (LSR) Concept", NASA TM 106158; Presented at the 26th IECEC, Boston, MA, August 4-9, 1991.
10. Rutledge, S., Forkapa, M., and Cooper, J. "Thermal Emittance Enhancement of Graphite-Copper Composites for High Temperature Space Based Radiators" AIAA/NASA/OAI Conference on SEI Technologies, Cleveland, Ohio, Sept 4-6, 1991.

CSTI HIGH CAPACITY POWER - THERMAL MANAGEMENT PROJECT ELEMENTS

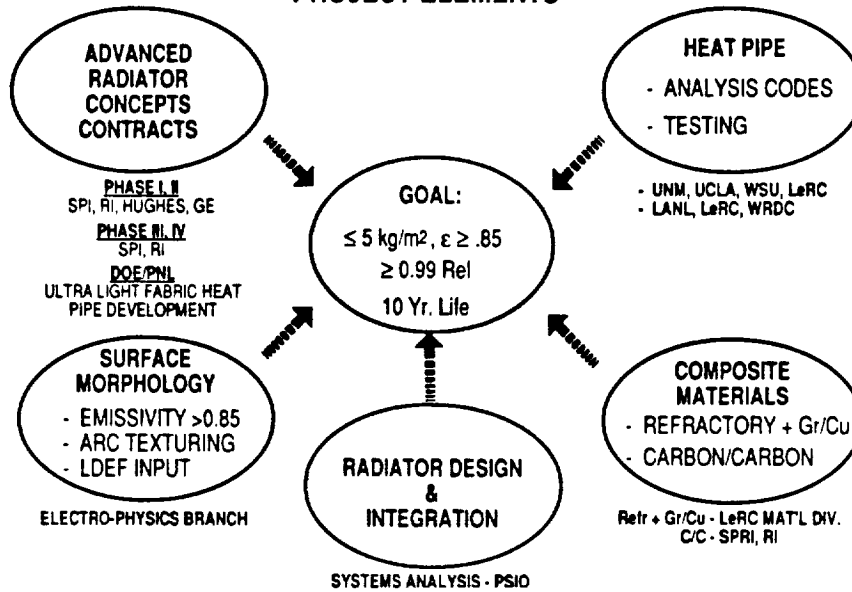


Figure 1: Thermal Management Project Elements

THERMAL MANAGEMENT BASELINE BUDGET

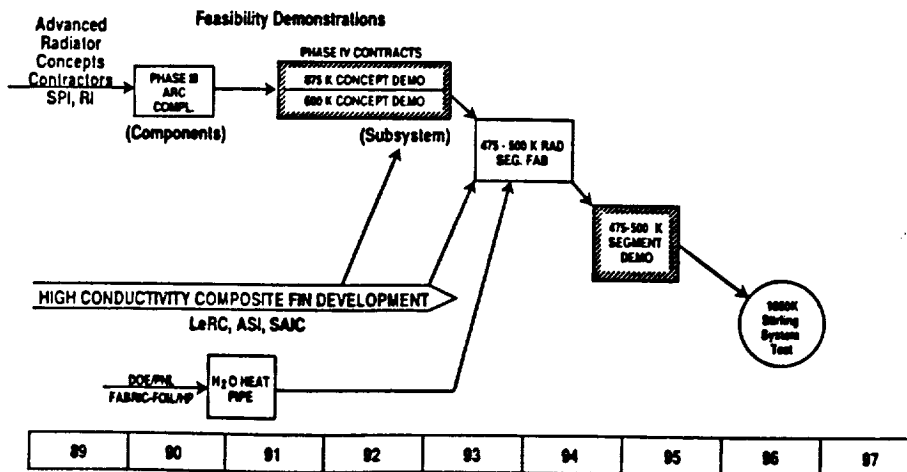


Figure 2: Thermal Management Project Plan

NASA ADVANCED RADIATOR CONCEPTS

Longitudinal Potassium Heat Pipes with Circumferential Heat Pipe Fins

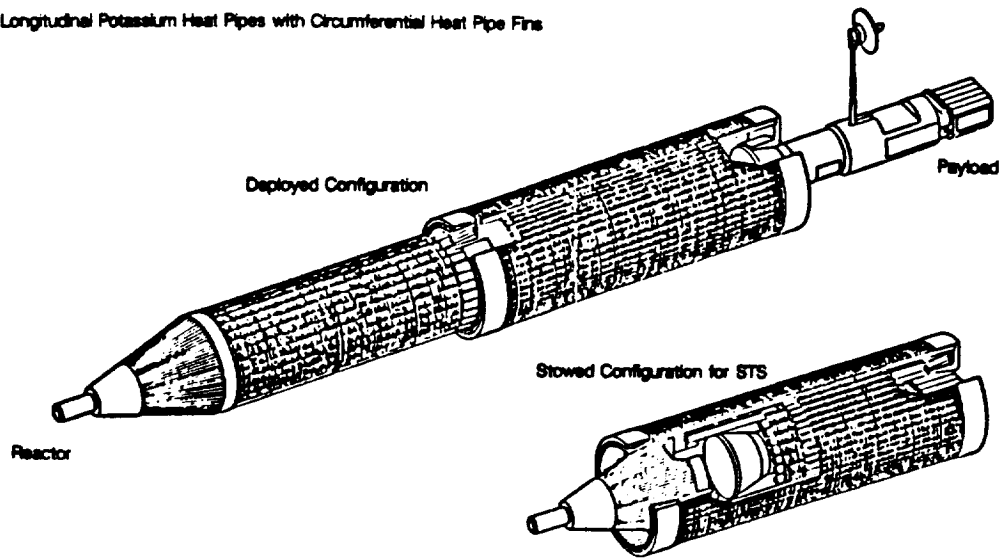


Figure 3: Multimegawatt Telescoping Radiator Concept for TE and LMR Space Power System

NASA Advanced Radiator Concepts

1.7 MW, 600 K Heat Rejection Radiator for Space Nuclear Stirling Cycle Power Systems

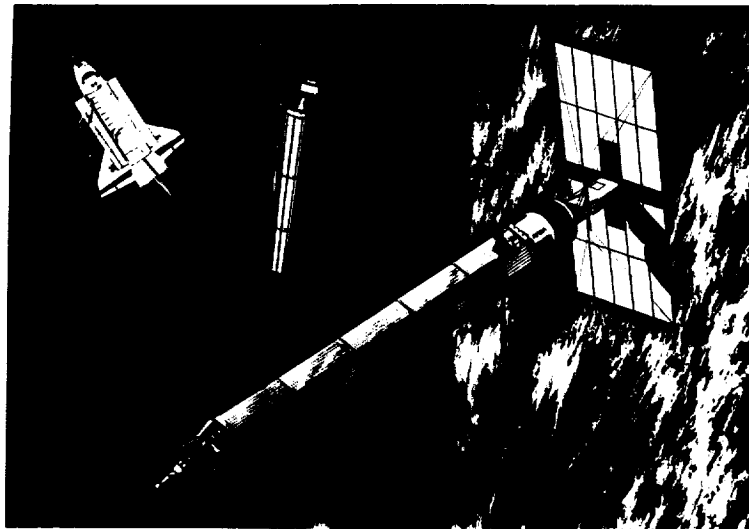


Figure 4: Folding Panel Radiator Concept for FPS and CBC Power Systems

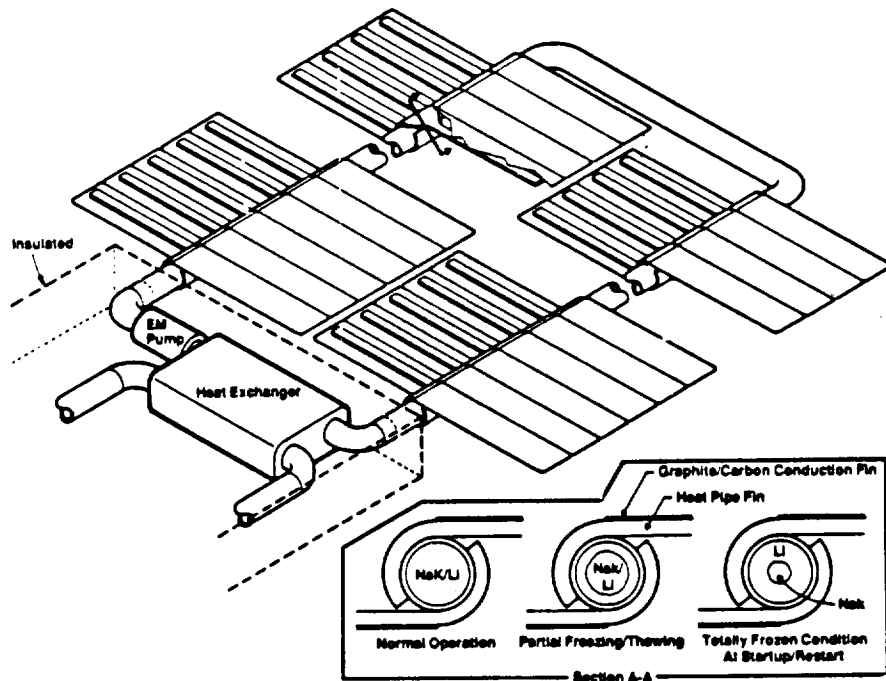


Figure 5: Pumped Li/NaK Binary Loop Radiator Concept Under Development at SPI

PUMPING CHARACTERISTICS OF LI/NaK MIXTURES

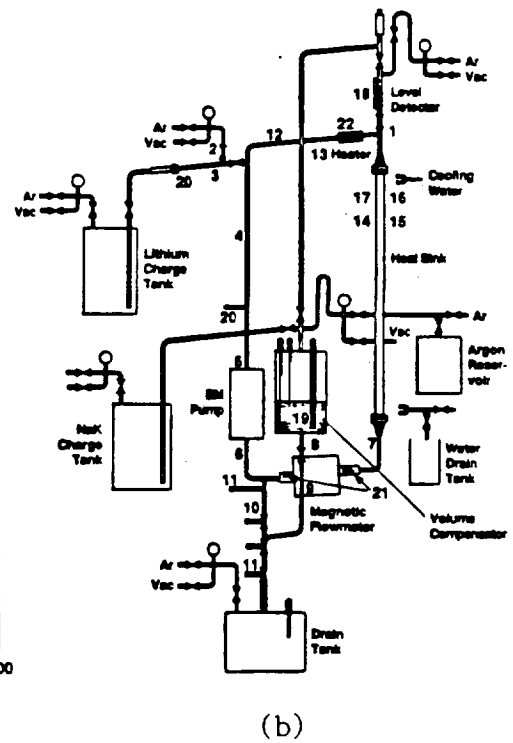
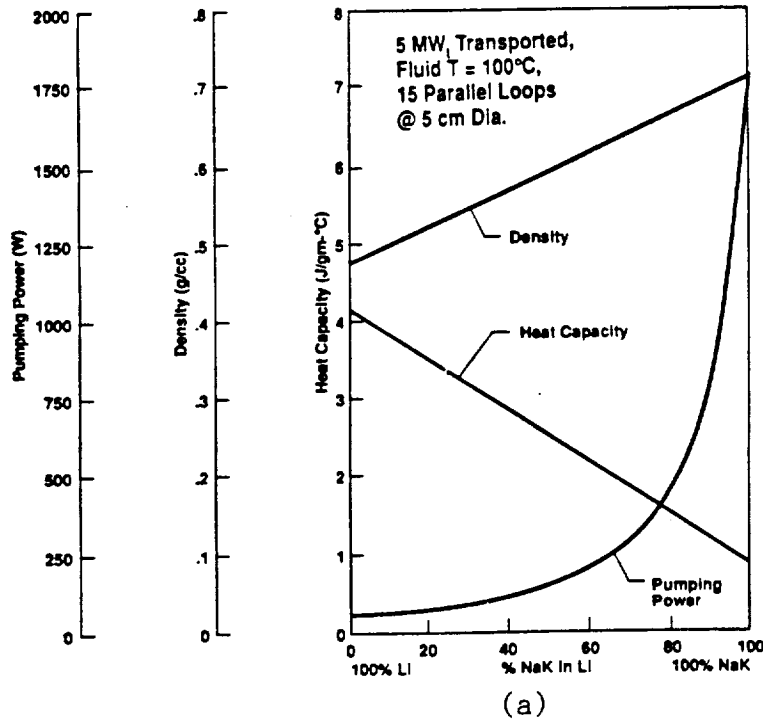


Figure 6: Binary Li/NaK Radiator Development (a) Design Characteristics; (b) Test Facility

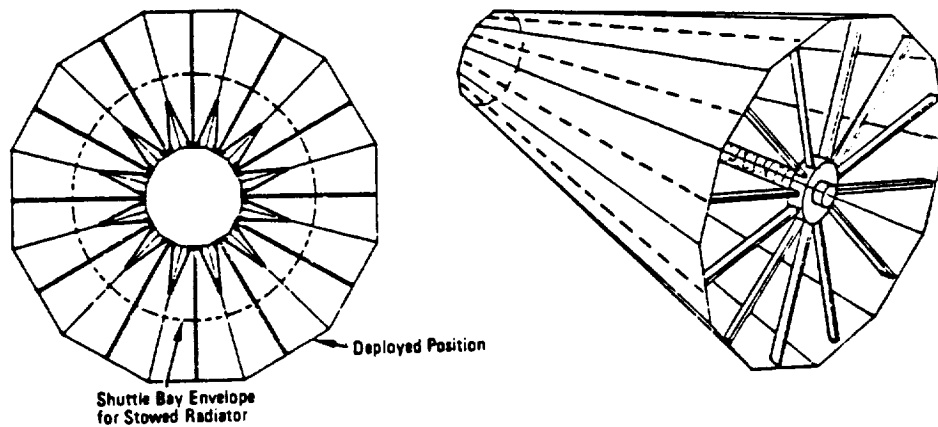


Figure 7: Cone-Petal Radiator Concept under Development at Rockwell International

ARC - ROCKWELL CONCEPT

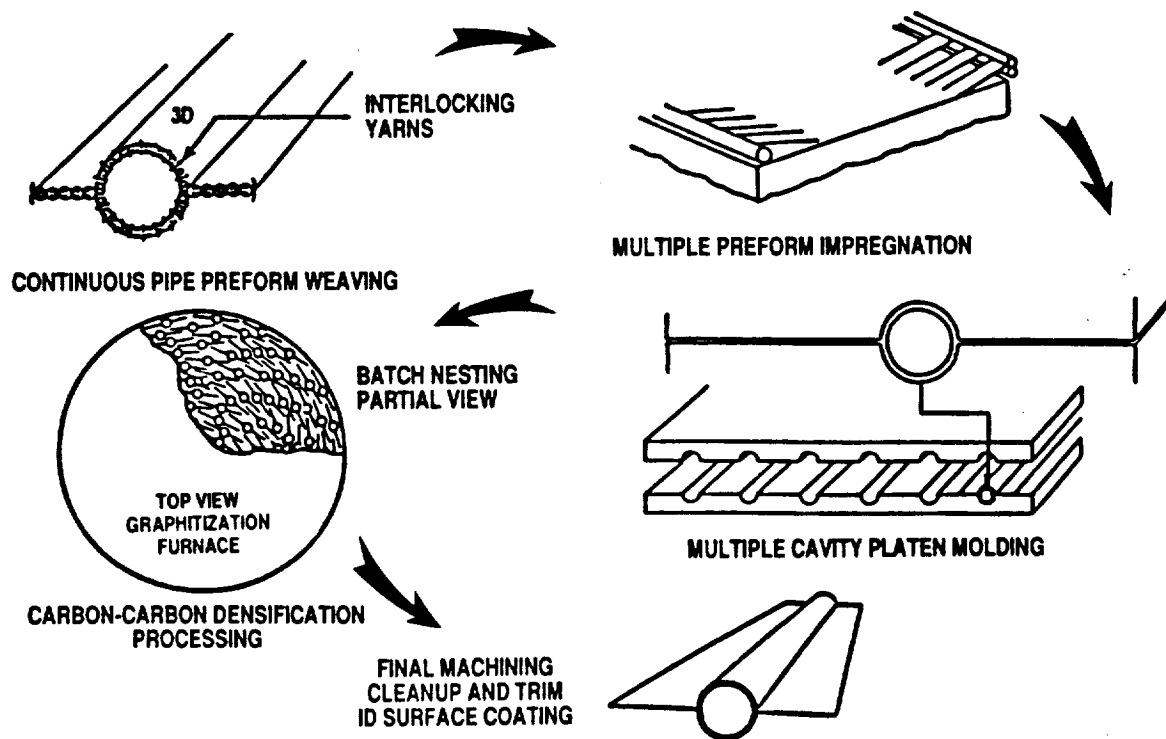


Figure 8: Finned Graphite/Carbon Heat Pipe Fabrication Process

**Effect of Reduction in Rad. Area on Stirling & Brayton, Pwr. & Eff.
(Constant Heat Rejection, $T_{hot}=1050\text{ K}$, Sink Temp.-250 K)**

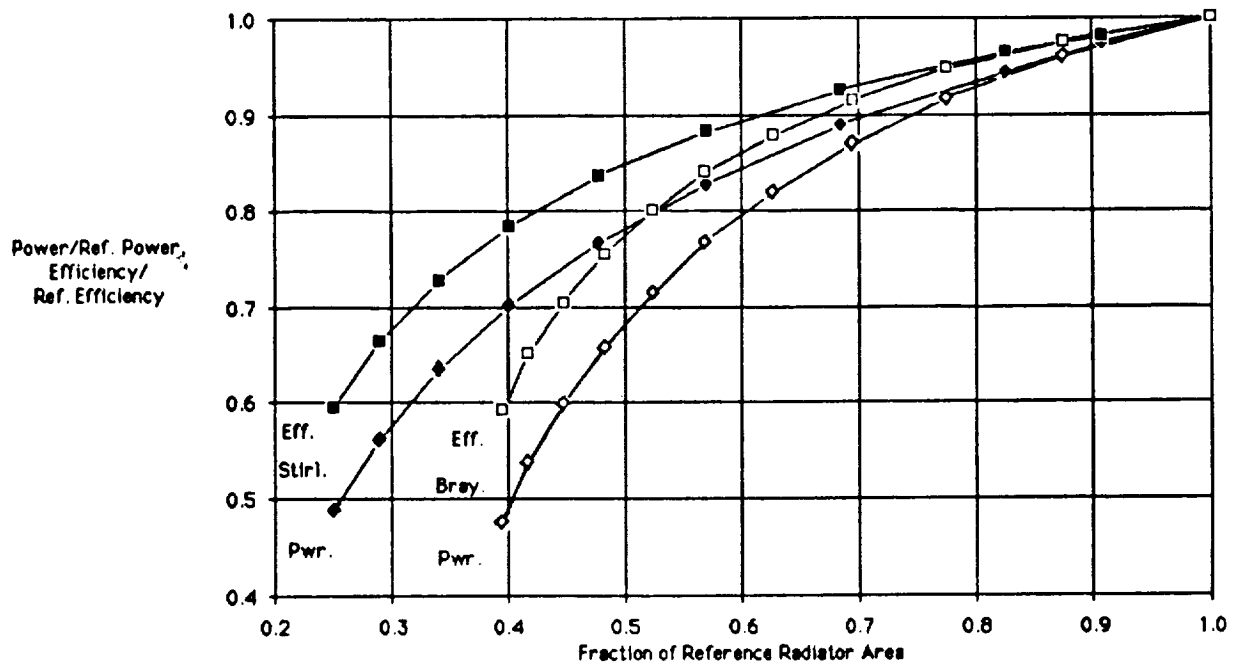
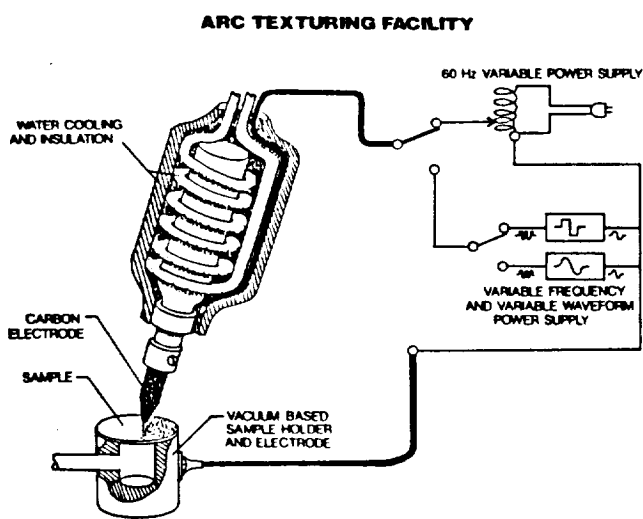
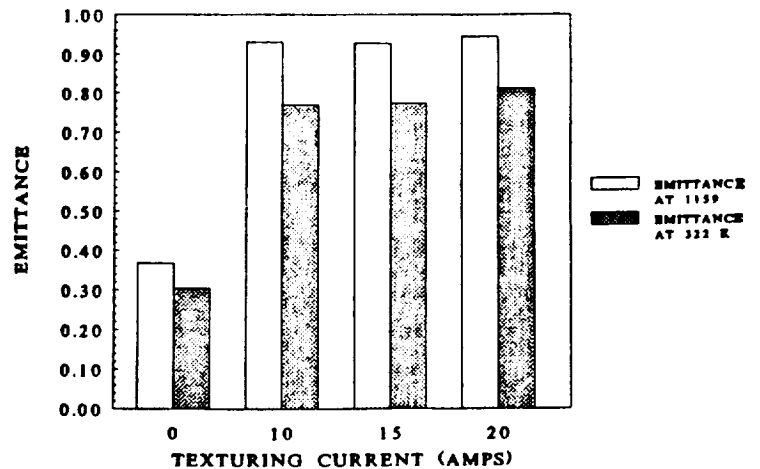


Figure 9: Radiator-Power System Integration Study
Sample Results



(a)

**ARC TEXTURED GRAPHITE-COPPER
AT A CONSTANT FREQUENCY OF 60 HZ**



(b)

Figure 10: Surface Emittance Enhancement by Arc Texturing
(a) Texturing Facility
(b) Emittance Enhancement of Gr/Cu Samples

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.				
1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE 1991		3. REPORT TYPE AND DATES COVERED Technical Memorandum
4. TITLE AND SUBTITLE An Overview of the Lewis Research Center CSTI Thermal Management Program			5. FUNDING NUMBERS WU-590-13-21	
6. AUTHOR(S) Albert J. Juhasz				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration Lewis Research Center Cleveland, Ohio 44135-3191			8. PERFORMING ORGANIZATION REPORT NUMBER E-6542	
9. SPONSORING/MONITORING AGENCY NAMES(S) AND ADDRESS(ES) National Aeronautics and Space Administration Washington, D.C. 20546-0001			10. SPONSORING/MONITORING AGENCY REPORT NUMBER NASA TM-105310 AIAA-91-3528	
11. SUPPLEMENTARY NOTES Prepared for the Conference on Advanced Space Exploration Initiative Technologies cosponsored by AIAA, NASA, and OAI, Cleveland, Ohio, September 4-6, 1991. Responsible person, Albert J. Juhasz, (216) 433-6134.				
12a. DISTRIBUTION/AVAILABILITY STATEMENT Unclassified - Unlimited Subject Category 20			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) This report presents an integrated multi-element project effort, currently being carried out at NASA LeRC, for the development of space heat rejection subsystems, with special emphasis on light weight radiators, in support of SEI power system technology, and in particular the SP-100 program. Principal project elements include both contracted and in house efforts. Included in the first category are two contracts, with Rockwell International (RI) and Space Power Incorporated (SPI), aimed at the development of advanced radiator concepts (ARC), and demonstration of a flexible fabric heat pipe radiator concept being conducted by DOE/PNL under an interagency agreement. In house work is designed to guide and support the overall program by system integration studies, heat pipe testing and analytical code development, radiator surface morphology alteration for emissivity enhancement, and composite materials research focussed on the development of light weight high conductivity fins.				
14. SUBJECT TERMS Spacecraft radiators; Thermal radiation; Heat radiators			15. NUMBER OF PAGES 12	
			16. PRICE CODE A03	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT	